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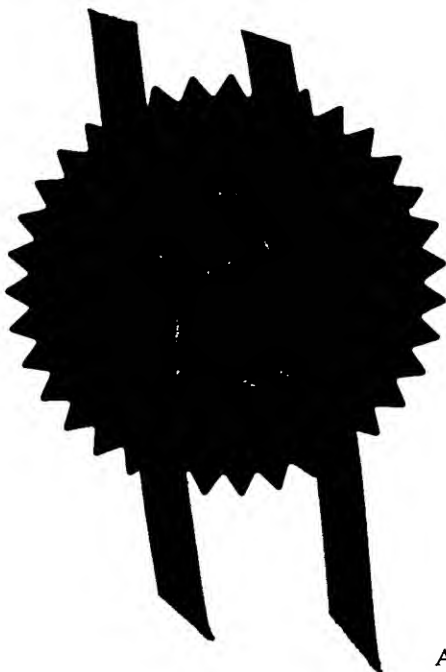
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1.	Your reference	N.76897 MN

2.	Patent application number *(The Patent Office will fill in this part)*	2 0 SEP 1999	**9922198.8**

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

ISIS INNOVATION LIMITED
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Patents ADP number *(if you know it)*   3998564001

THE PATENT OFFICE
20 SEP 1999
LONDON

If the applicant is a corporate body, give the
country/state of its incorporation

The United Kingdom

4. Title of the invention

POROUS FILTER ELEMENT AND METHOD OF
FABRICATION THEREOF

5. Name of your agent *(if you have one)*

J A KEMP & CO

"Address for service" in the United Kingdom to
which all correspondence should be sent
(including the postcode)

14 SOUTH SQUARE
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LONDON WC1R 5LX

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		Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*
6.	If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number			

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Porous Filter Element And Method
Of Fabrication Thereof

The present invention relates to a porous filter element and in particular to a method of manufacturing such a filter element.

There are many different types of porous filter element, ranging from the relatively unsophisticated and familiar filter papers, and filters made of felt and woven materials, to more sophisticated filters formed from, for example, porous films, such as nucleopore filters and Anotech filters (made from an aluminum oxide film).

Nucleopore filters are made by bombarding a polymer film with alpha particles and then etching the regions damaged by the alpha particles to produce holes. Because the pattern of holes is random, the intensity of alpha particles has to be kept low to avoid holes running into each other. Thus the filter produced can only have a low porosity if hole uniformity is to be maintained.

The present invention is concerned with a new way of making a porous filter element, which gives close control over the shape and arrangement of the pores, and which is capable of making a filter with a highly regular and controllable array of pores over a large range of scales down to the microscopic.

In the present invention this is achieved by using a photosensitive material, such as a photosensitive resin, as the starting material, and exposing this starting material to an interference pattern of electromagnetic radiation so that different areas of the photosensitive material are exposed differently according to the variation in intensity caused by the interference. The material is then treated, e.g. using a chemical solvent, to remove selectively regions which have been exposed by an amount which is greater or less than a predetermined critical amount, this treatment leaving voids in the material. The material can then be used either directly as a filter element, or it can be used as a mould to produce a filter element, for instance by filling the voids with a material which solidifies, and then removing the original photosensitive material.

Because the array of pores is defined by the interference pattern of e.m.

radiation, e.g. u.v. light, controlling this pattern gives close control over the shape, size and disposition of the pores. Interference patterns are highly regular and so a highly regular array of pores can be created.

The interference pattern can be created as a 3-D pattern in the photosensitive material by interfering three or more coherent or partially coherent laser beams therein. The pattern can be arranged to vary only in two dimensions, with it being substantially constant in the third dimension (which may correspond to the normal to the surface of the filter), so that the result of selective removal of material is an array of constant cross-section channels extending through the material from one side of the material to the other. Alternatively, it is possible to arrange for the interference pattern to vary in the third dimension also by use of at least four interfering beams, creating a pattern of interconnecting voids in the material which varies in all three dimensions.

An alternative method for producing an interference pattern that varies in two dimensions and does not require a coherent light source is a grating interferometer, for example as described by Berger and co-workers [J. Appl. Phys. vol. 82, p.60-64 (1997)]. Alternatively, a pattern of exposure that varies in two dimensions may be created by superposition of two or more exposures that vary periodically in intensity in one dimension, but have different orientations.

For a given wavelength of e.m. radiation, the angles between the interfering beams decide, and can be used to control, the period of the interference pattern. The overall intensity of the interfering beams or the exposure time or the chemical composition of the photo resist can be changed to change the pore size by varying the amount of material which is exposed by more than the critical amount (and thus the amount which is removed in the treatment step). Thus for a fixed periodicity the pore size is continuously variable.

The relative polarization and relative intensity of the interfering beams can be varied to adjust the shape of the pores by varying the pattern of interference.

Thus this close control of pore size and shape, with absolutely regular periodicity, allows the pores to be packed very closely together and sized to make a high throughput yet fine filter without the problem of pores joining together found in a random creation process.

Of course, in practice the interference pattern may only be created in a part of the body of photosensitive material. The rest can be used as an integral support or the porous part of the body can be cut out for use as a filter element.

Depending on the nature of the photosensitive material used, it is possible that either regions which are subject to an exposure greater than a predetermined amount, or less than a predetermined amount, are removed by the treatment step. For instance, the material could be a resin in which cross-linking occurs on exposure to light, with non-cross-linked regions then being removed by using a suitable solvent, to create pores corresponding to the dark regions of the pattern.

The resin can contain a photosensitive agent which responds to the light and then causes cross-linking to occur either straightaway or on application of heat. In this way the pattern forms a "latent image" in the resin, which is developed subsequently by heating and chemical treatment.

Alternatively the photosensitive material can be one in which the exposure to light increases its solubility (either directly or via a photosensitive agent) by, for example, reducing the degree of cross-linking or by changing its polarity, in which case the pores will correspond to the light regions of the pattern.

The photosensitive material may conveniently be prepared in the form of a thin film (e.g. by spinning or spreading using a roller or blade), which is then exposed to the interference pattern.

Where the exposed and treated photosensitive material is to be used as a mould to form a filter element, the voids in the material can be filled with an inert material such as a metal, e.g. nickel, silver or gold, (which can be introduced by electrochemical or electroless deposition) or a ceramic, the photosensitive material then being removed. Where a ceramic is used, which is solidified by sintering, the sintering process is also effective to burn off the original photosensitive material.

The invention is capable of producing porous filter elements in which the pores consist of very long narrow channels through the element. For instance, the channels can have a diameter of the order of 0.1 micrometers, with a spacing of the order of 0.5 micrometers, in a filter element of thickness of the order of 30 micrometers. On the other hand, the same method is also capable of producing much

larger scale filters with regular arrays of pores over a large area.

The invention will be further described by way of non-limitative example with reference to the accompanying drawings in which:-

Figure 1 schematically illustrates the arrangement used to expose the photosensitive material;

Figure 2 schematically illustrates a first filter element according to the invention;

Figure 3 illustrates a second filter element made according to the invention;

Figure 4 is a scanning electron micrograph of a filter element of the type illustrated in Figure 2; and

Figure 5 is a scanning electron micrograph which shows the element of Figure 4 fractured; and

Figure 6 shows a simulation of an element with circular channels.

Figure 1 schematically illustrates the arrangement for exposing a body 1 of photosensitive material to a desired light pattern. As will be explained below, the body 1 of photosensitive material can be in the form of a spun film. In Figure 1 the light pattern is illustrated as being created by interference pattern of three laser beams 3, 5 and 7. It will be appreciated that in this arrangement, in which the angles between the light beams are determined by mirrors and not by diffraction from a grating, the beams need to be coherent or partially coherent and conveniently this can be achieved by beam splitting from a single laser source. This allows easy control of the overall intensity, e.g. by positioning crossed-polarizers before the beam splitter, and the intensity, polarization and angle of incidence of each beam is also adjustable using standard optical elements. As shown in Figure 1 the beams come together in the body of photosensitive material to create in the material an interference pattern, which consists of a pattern of spatially varying intensity, in region 9. Thus the exposure (or radiation dosage) of the material in this region varies spatially.

The use of three beams creates an interference pattern which varies in two orthogonal directions within the material, but not in the third orthogonal direction. Thus regions of constant exposure can be made to extend linearly through the depth of the material in a direction which connects one side to the other. Usually this

direction will be perpendicular to the plane of the film, but it may also be slanted with respect to the perpendicular, should this be advantageous.

After sufficient exposure the exposed photosensitive material is treated, for instance by chemical development, to selectively remove regions of the material in dependence upon their exposure. Where, as explained below, the photosensitive material is a resin which cross-links in response to a certain exposure to light, the chemical development consists of removing using a solvent those regions which have not received a sufficient exposure to cross-link sufficiently (i.e. corresponding to the dark regions in the interference pattern). Although the intensity in an interference pattern varies smoothly, the response of the photosensitive material is non-linear so, the division between those parts of the material which have received a sufficient dose, and those which have not, is sharper than the variation in intensity of the interference pattern. Thus the effect of chemical development is to produce clearly defined voids in the material.

The necessary dosage of radiation can be applied either in a single exposure or in more than one exposure. The use of multiple exposure can increase the variety of structures which can be produced because the structure will correspond to a combination of different interference patterns, rather than to a single interference pattern.

Of course the region 9 in which interference occurs will generally be only a part of the prepared body of material 1. After chemical development this region may be cut-out and used. Alternatively the surrounding region can be uniformly exposed (or not) to create an integral support for the porous region.

The photosensitive material may be one which possesses an average number of crosslinkable groups per molecule of at least 3.0 with an equivalent weight per crosslinkable group of at most 1000. It has been found that with high functionality the network of crosslinks formed is potentially very dense giving high solubility contrast between strongly and weakly exposed material.

In general the photosensitive materials used in this invention are those possessing an average number of crosslinkable groups per molecule of at least 4, preferably at least 6 and especially about 8. They have an equivalent weight per

crosslinkable group (XEW) in general at most 500, typically at most 400, preferably at most 300, especially at most 230. Suitable photosensitive materials which can be used include epoxy resins ie. epoxy groups act as the crosslinkable groups.

5   It has been found that it is particularly advantageous to use the glycidyl ether of bisphenol A novolac which is available as EPON-SU-8 from Shell Chemicals. This resin has low intrinsic absorption at the laser wavelength (λ = 355 nm) and is capable of sub 0.1 micron resolution. It has an average of 8 epoxy groups per molecule. The material is therefore mostly in the form of a tetramer although other oligomers will usually be present. Its XEW is generally about 215, with a typical

10   range from 190 to 230. It may be desirable to co-polymerise this material with a less crosslinkable plasticising epoxy monomer e.g. one with a single epoxy group in order to minimise shrinkage and/or film distortion on heating of the material (thereby reducing the functionality somewhat). Alternatively, the resin can be modified by using a so-called "expanding" monomer such as a spiro-orthocarbonate.

15   Alternatively, improved physical properties of the polymer can be obtained by the addition of a binding agent such as a linear polymer. Effectively, any polymer can be used provided that it has sufficiently high functionality and the precursors have a low degree of optical absorption at the laser wavelength within a film typically 10-100 microns thick.

20   In one preferred embodiment of the present invention the photosensitive material is subjected to irradiation in the presence of a photo acid generator. Subsequent to exposure the material is heated to cure the crosslinked material.

Suitable photoacid generators which can be used, especially with epoxy resins, include onium salts such as triaryl sulfonium salts including triphenyl

25   sulfonium antimony chloride which is available as Cyracure UV1 from Union Carbide. This particular generator is well suited to irradiation at 355 nm where it has sufficient absorption (molar extinction coefficient ~ 300 mol^{-1} dm^3 cm^{-1}). In general the molar extinction coefficient of the PAG should be from 50 - 2000 $mol^{-1}dm^3cm^{-1}$ at the laser wavelength. If the molecular coefficient is too large, the requirement for

30   the sample to be optically thin means that the concentration of initiators is too small to effect polymerisation. On the other hand if it is too small, the PAG concentration

is so high that it adversely affect the properties of the polymer. By "optically thin" is meant that at the concentration at which it is used the PAG does not absorb more than 5% of the radiation which is incident upon it. In addition the quantum efficiency of the PAG should be sufficient for the exposure to cause insolubilisation

5 of the photosensitive material. The effective quantum efficiency will be enhanced if the system involves chemical amplification. Obviously sufficient photosensitive material must be insolubilised to provide a volume of insolubilised material which is useful for practical purposes i.e. a useful volume, for example 1 mm³ e.g. a film of size 5 x 5 x 0.04 mm. By "cause insolubilisation" is meant that there is sufficient

10 proton generation for subsequent acid catalysed polymerisation, as discussed below, to result in a crosslinked material which is insoluble in a solvent which dissolves the unirradiated or weakly irradiated material. One of skill in the art will, of course, be able to select an appropriate PAG from those possessing the required molar extinction coefficients and optical thinness. For SU-8 a quantum efficiency of about

15 0.2 is needed for proton generation in the PAG. It is believed that the insolubility threshold is reached when each absorbed photon leads to the conversion of material equivalent to about 250 or 500 crosslinkable groups, for example about 600 epoxy groups, into insoluble polymer.

A specific example of the materials and process used to produce a filter

20 element (actually the one shown in Figures 4 and 5) will now be described.

The photosensitive material was prepared by dissolving Epon-SU8 resin (Shell Chemicals), the glycidyl ether of bisphenol-A novolac, in γ-butyrolactone (50-60% wt. solids) with gentle heating (~30-40°C) and manual stirring. The resulting viscous solution was filtered to exclude particles larger than 1 μm. Between 0.5% wt.

25 and 3% wt. of a photoacid generator (PAG), a triaryl sulfonium salt (Cyracure UV1 from Union Carbide) was added to the solution. The amount of PAG added determines the sensitivity of the photoresist, with 1.2% giving good results for these experimental conditions. The resulting photoresist was mixed thoroughly (and can be stored in the dark and away from heat sources until required).

30 Solid films of the photoresist (2-30 μm for the 50% wt. resist and 10-60 μm for the 60% wt. resist) were prepared by spinning the resist onto fused silica disks

(~2 cm diameter). For example to prepare a ~30 μm film, approx. 2 ml of the photoresist is pipetted onto the disk so that it is flooded. The film is then spun at 1000 rpm (5s ramp up, 40s hold, 5s ramp down) and then undergoes a post application bake (PAB) at 50°C for 5 mins followed by 15 mins at 90-100°C to

5   evaporate the solvent. The interval between film preparation and exposure is kept as short as possible and generally less than 30 mins. Films can also be prepared by spreading, moulding or pouring.

The film was then exposed to an interference pattern created at the intersection of three beams from a frequency-tripled, injection seeded, Q-switched

10   Nd:Yag laser (wavelength λ=355 nm). Such a pattern has two dimensional periodic translational symmetry.

The propagation directions, polarisation directions and relative intensities used are defined as follows:-

Normalised optical wave-vectors (relative to the conventional fcc unit cell

15   axes):

(1)	-0.96225038	-0.19245008	-0.19245008
(2)	-0.19245008	-0.96225038	-0.19245008
(3)	-0.19245008	-0.19245008	-0.96225038

Polarisation unit vectors (in the same frame):

(1)	0.269517	-0.575382	-0.772202
(2)	0.804841	-0.0425761	-0.591961
(3)	0.933817	-0.337270	-0.119310

Relative intensities $(I_1:I_2:I_3)$; (1:1:1)

These polarizations and relative intensities create essentially triangular

25   channels (though with rounded corners). Varying the polarizations and relative intensities can create circular or elliptical channels, or other shapes as desired.

For instance circular channels as shown in Figure 6 can be created by using the following polarisation vectors:-

(1)	0.0000000	-0.7071068	0.7071068
(2)	0.7071068	0.0000000	-0.7071068
(3)	-0.7071068	0.7071068	0.0000000

The films were exposed in a single pulse (6 ns) of the laser. The total dose can be varied from 80-200mJcm^{-2} depending on the required polymer/air ratio in the filter. (The filling factor is also related to the time and temperature of the post exposure bake). The glass substrate was index matched to a thick glass block using mineral oil in order to reduce back reflections.

The beam geometries described above are those required to define the appropriate interference pattern in air. In practice refraction occurs as the beam enters the film of resist but it is possible to compensate for the refraction by changing the angle of the beams. This can be done, for example, by adding a shaped transparent optical element or elements with refractive index greater than unity into the beam paths, and may include the use of high index liquid between rigid optical elements.

The pulse duration is not critical. With an injection seeded laser the coherence length is equal to the pulse length, but this requirement can be relaxed if the optical path-lengths are made accurately equal. A cheaper but less effective option for increasing the coherence length is etalon-narrowing. In practice it is only necessary to achieve a coherence length of ~1cm. An ordinary un-narrowed Q-Switched Nd-YAG laser can approach this requirement. More importantly though injection-seeding makes the pulse energies, following third harmonic generation, far more reproducible, so that the control of the dose in a single pulse exposure becomes straightforward. A further advantage of single pulse operation is the absence of significant refractive index changes, that could perturb the interference, during the exposure.

Alternative light sources can be used, providing the photoinitiator is chosen to match the operating wavelength. An optical parametric oscillator or alternative laser which is continuously tunable, could therefore be used to construct filters with different spacings of pores, with or without a change in the angles between the interfering beams.

The exposure of the resist results in the production of a proton from the photochemically induced fragmentation of the PAG molecule. Acid catalysed polymerisation of the SU8 resin occurs in a post exposure bake (PEB). The glass

substrate was placed directly on a level hotplate at 40-120°C for between 1-20 mins depending upon the exposure dose, % PAG in the resist and the required filling factor. An PEB temperature below the melting point of the SU8 resin (80-90°C) results in a much "cleaner" lattice than one produced with a PEB above the resin's

5 melting point.

The film was then developed in propyl glycol methyl ether acetate (PGMEA) in an ultrasonic bath to dissolve away the uncrosslinked resin. During development the film becomes detached from the substrate. The ultrasonic power was damped or attenuated to ~7 W to avoid mechanical damage to the film as it releases from the

10 substrate. The bath was thermostated at 40-50°C and a typical development time is 40 mins for a 30 μm film. After the bath development, the film was washed with fresh PGMEA and finally rinsed in isopropyl alcohol before drying in air.

The resulting porous element is illustrated schematically in Figure 2. The body of photosensitive material 1 has an array of parallel channels 13 extending from

15 one side to the other. A scanning electron micrograph of the actual filter element produced by the above method is shown in Figure 4. It is shown at higher magnification and fractured in Figure 5, where the channels 13 can easily be seen. It will be noted that the array is very regular, and that the channels are extremely narrow compared to their length.

20 The above example creates uniform channels through the filter. It is possible though, to vary the shape of the channels with depth. A schematic illustration of such a filter element is shown in Figure 3. It can be seen that the channels have a narrow section 15 at one end, which communicates with a wider section 17. If this is used to filter material passing from top to bottom in the orientation illustrated in

25 Figure 3, it is a "non-blocking" filter. This can be produced in several ways. For instance, the photosensitive material 1 can have two layers of differing compositions. The top layer, which will form the narrowed part of the channel, has more PAG than the lower layer, so more cross-linking occurs on exposure, thus resulting in narrowed holes.

30 Alternatively a different intensity of illumination can be created in the region desired to have narrow holes, for instance a greater intensity there can be achieved by

uniformly exposing that surface with a shorter wavelength light which does not penetrate far into the photosensitive material, or with an evanescent wave whose field penetrates a short distance into the photosensitive material.

The filter element made using the techniques above can be supported for use on a porous substrate having larger pores than the filter to provide a non-blocking arrangement. The substrate can be made by the same technique, or by one of the standard techniques for making filters.

It will be appreciated that the invention is not limited to the materials described in the above example. For instance other epoxies or other photosensitive materials can be used, and as mentioned the process can be changed so that the degree of polymerisation/cross-linking in the material is higher in the regions of lower exposure to light, than it is in the regions of higher exposure to light. Thus both "negative" and "positive" processes are possible.

Further, although the above example uses a very fine interference pattern to create a very fine filter, the method is equally applicable to much larger scales, simply by producing an interference pattern of the desired scale.

The porous element made by the above method can be used directly as a filter element. Alternatively the technique can be used to make a mould from which a filter element of another material is created. For instance, an element produced using the materials above can have the voids filled with a ceramic such as titanium (IV) oxide and then be heated (e.g. to 575°C) to burn off the resin mould and sinter the ceramic. As an alternative to using a ceramic the voids in the resin can be filled with a material which is insoluble in a solvent for the resin. The resin can then simply be dissolved away. Of course, it is necessary either that the voids in the element are connected together so that the solidified filling will support itself when the resin is removed, or some other support must be provided for the solidified filling. It will be appreciated that the specific element produced by the method above and illustrated in Figure 4 would mould a disconnected array of upstanding "rods" which are not self-supporting. Connectivity can be achieved by varying the interference pattern so that the "rods" become connected (without losing porosity). Alternatively the "rods" could be formed on a substrate which supports them.

CLAIMS

1. A method of fabricating a porous filter element comprising the steps of: exposing a photosensitive material to an interference pattern of electromagnetic radiation, whereby the exposure through the material varies in accordance with the spatially varying intensity created by the interference; and treating the exposed photosensitive material to selectively remove regions of the material in dependence on the exposure to which that region was subject.

2. A method of fabricating a porous filter element according to claim 1, wherein the interference pattern is created by exposing the material to interfering beams of electromagnetic radiation.

3. A method according to claim 2 wherein at least one of the relative polarization, relative intensity, coherence and angles between the beams are selected in accordance with the desired pattern.

4. A method of fabricating a porous filter element according to claim 2 or 3, wherein the beams of electromagnetic radiation are laser beams.

5. A method of fabricating a porous filter element according to claim 4, wherein three non-coplanar laser beams are used to create the pattern, the three beams having equal intensities.

6. A method according to claim 5 wherein the beams have the following wave vectors and polarization unit vectors relative to conventional f.c.c. unit cells axes:

Normalised optical wave-vectors:

(1)	-0.96225038	-0.19245008	-0.19245008
(2)	-0.19245008	-0.96225038	-0.19245008
(3)	-0.19245008	-0.19245008	-0.96225038

Polarization unit vectors:

(A)	(1)	0.269517	-0.575382	-0.772202
	(2)	0.804841	-0.0425761	-0.591961
	(3)	0.933817	-0.337270	-0.119310
or (B)	(1)	0.0000000	-0.7071068	0.7071068
	(2)	0.7071068	0.0000000	-0.7071068
	(3)	-0.7071068	0.7071068	0.0000000

7.   A method of fabricating a porous filter element according to any one of the preceding claims, wherein the regions extend in a straight line from a first side of said photosensitive material to a second, opposite side of said material.

8.   A method of fabricating a porous filter element according to any one of the preceding claims, wherein the step of treating the exposed photosensitive material to selectively remove regions thereof comprises removing regions having an exposure below a predetermined level.

9.   A method of fabricating a porous filter element according to any one of the preceding claims, wherein the step of treating the exposed photosensitive material to selectively remove regions thereof comprises removing regions having an exposure above a predetermined level.

10.   A method of fabricating a porous filter element according to any one of the preceding claims, wherein the pattern is substantially non-varying through the depth of the material whereby said regions have a constant cross-section through the material.

11.   A method of fabricating a porous filter element according to any one of claims 1 to 9, wherein the pattern varies through the depth of the material to vary the cross-section of said regions through the depth of the material.

12. A method of fabricating a porous filter element according to claim 10 or 11, wherein the pattern repeats across the material perpendicular to the depth direction to create in the material a regular array of identical regions which extend through the depth of the material.

5

13. A method of fabricating a porous filter element according to any one of the preceding claims, wherein the material is a mixture of an epoxy resin and a photoacid generator.

10

14. A method of fabricating a porous filter element according to any one of the preceding claims, wherein the material to be exposed is in the form of a thin film.

15. A method of fabricating a porous filter element according to any one

15 of the preceding claims wherein the photosensitive material comprises a plurality of regions of different composition such that the different regions react differently to exposure followed by treatment.

16. A method of fabricating a porous filter element according to claim 15

20 wherein the regions are layers, one on top of the other.

17. A method of fabricating a porous filter element according to any one of the preceding claims, comprising the further step of using said treated material as a lost mould to form a porous filter element.

25

18. A method of fabricating a porous filter element according to claim 17, wherein the voids left by said selective removal are at least partly filled with a material from which the filter element is to be formed, and then the exposed and treated photosensitive material is removed.

30

19. A method of fabricating a porous filter element according to claim 18,

wherein the voids are filled with a ceramic which after introduction into the voids is sintered, said sintering burning off the exposed and treated photosensitive material to leave the ceramic porous.

5   20.   A method according to any one of the preceding claims wherein the exposure time and/or intensity of the e.m. radiation is set selectively in accordance with the desired size of the regions.

         21.   A porous filter element made by the method of any one of the

10   preceding claims.

         22.   A method of fabricating a porous filter element, the method being substantially as hereinbefore described with reference to the accompanying drawings.

15   23.   A porous filter element constructed and arranged to operate substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

ABSTRACT
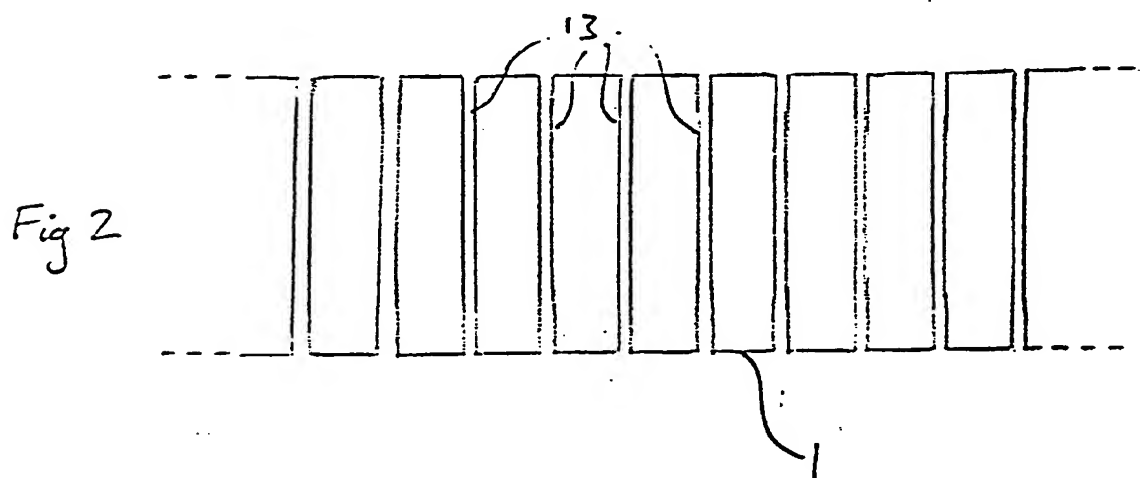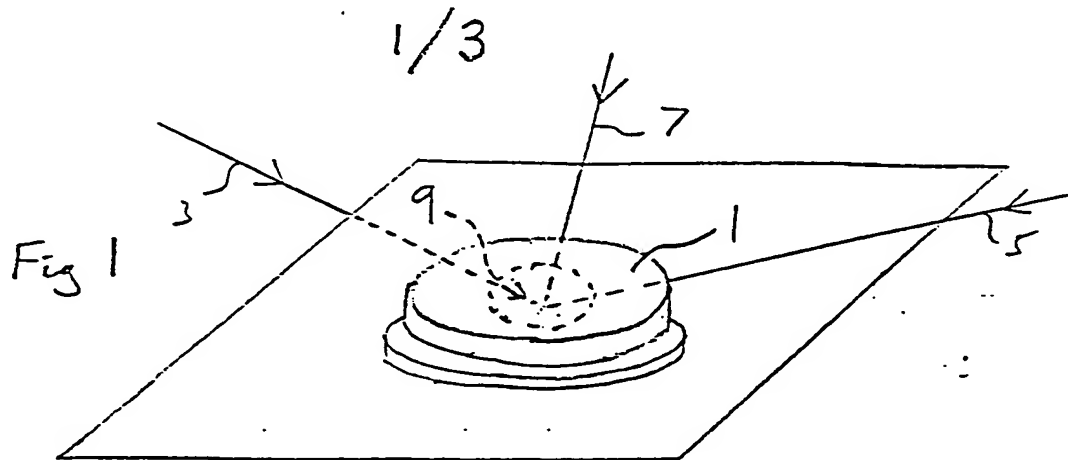
Porous Filter Element And Method
Of Fabrication Thereof

A method of making a porous filter element by defining in a body of photosensitive material a pattern of varying intensity e.m. radiation (e.g. light), by creating an interference pattern in the material. After exposure to the e.m. radiation, regions of the material are selectively removed (e.g. dissolved away) in dependence upon the exposure to which they were subject. This results in a porous element which can be use directly as a filter element, or which can be used as a lost mould to create a filter element from a different material. In that usage the voids in the resin material are filled with the material from which it is desired to make the filter, and then the resin is removed. Varying the intensity and the pattern varies the size, shape and disposition of the regions which are removed, and thus of the pores in the filter.
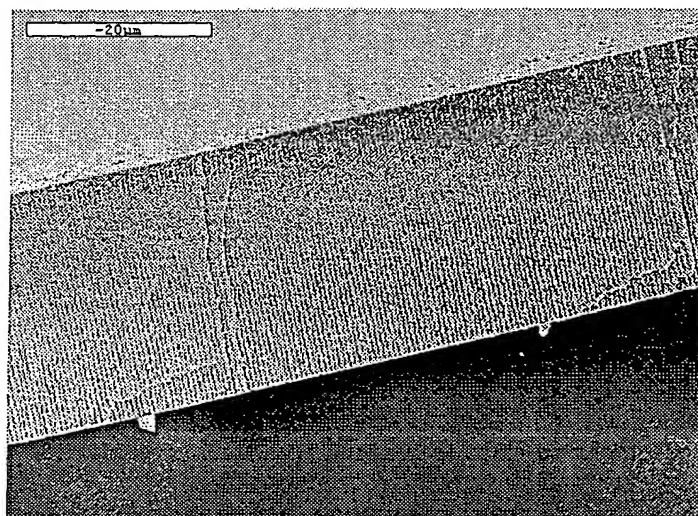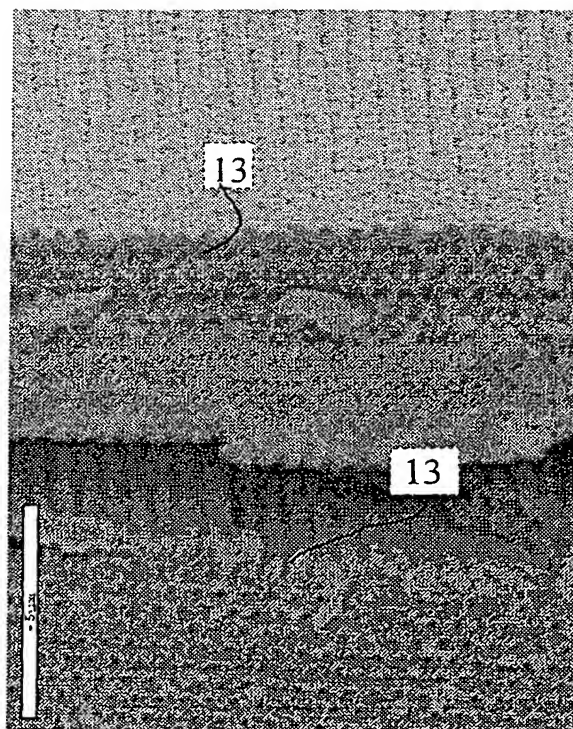
Figure 5

Fig 1

Fig 2

Fig 3
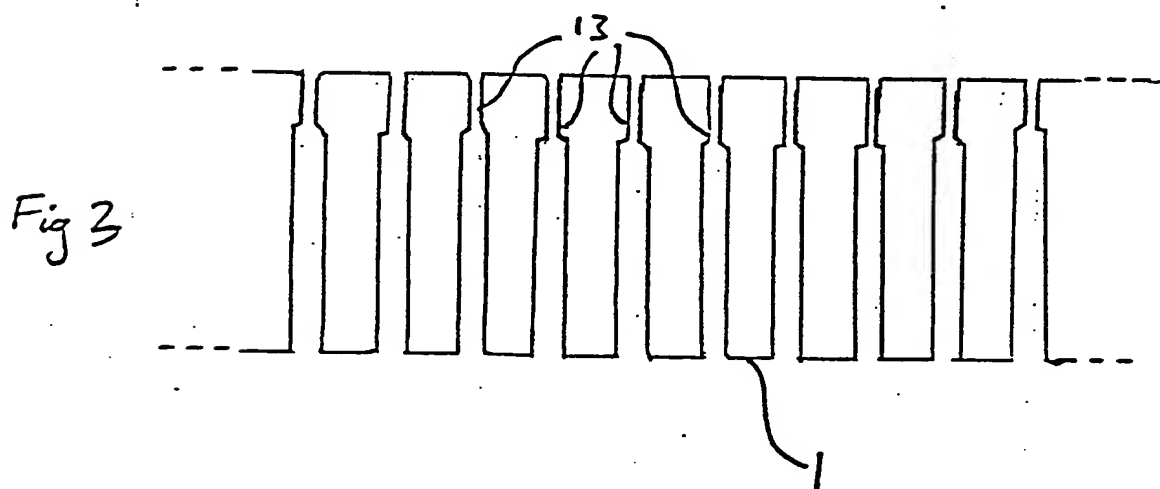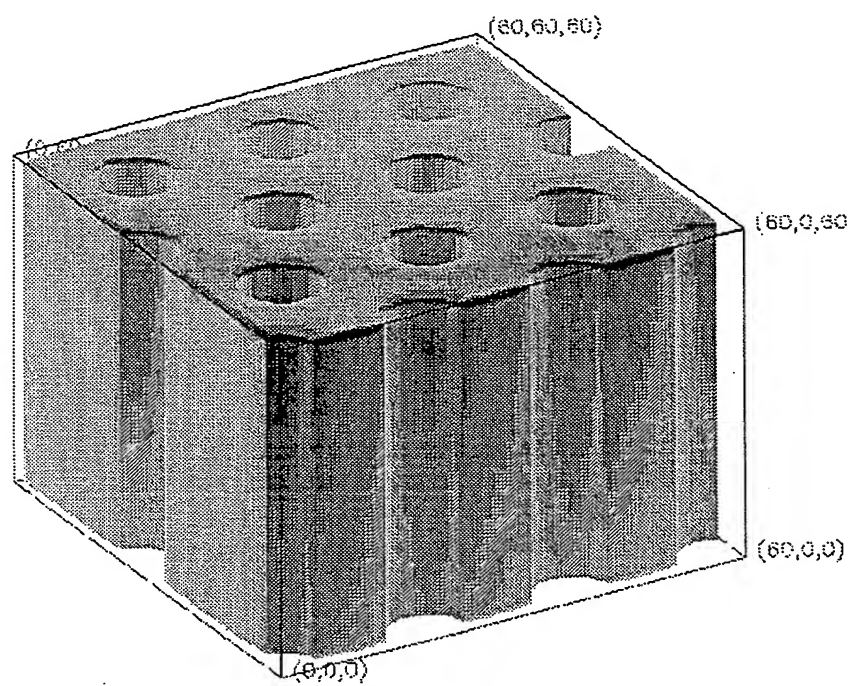
Figure 4

Figure 5

Figure 6